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## Original research article

## The money or the trees: What drives landholders' participation in biodiverse carbon plantings?



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## HIGHLIGHTS

- A BBN model was constructed based on a literature review, interviews and expert elicitation.
- Program characteristics are more influential at driving participation than financial incentives.
- Biodiversity co-benefits is another important factor.
- Combining biodiversity incentives with flexible permanence options increases program adoption.

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## ABSTRACT

Carbon farming programs typically aim to maximise landholder participation rates to achieve desired environmental outcomes. This is critical for programs aiming to tackle both climate change and biodiversity loss simultaneously, as landholder participation in those schemes directly determines the level of carbon sequestered and the potential biodiversity gains. Biodiverse carbon planting is a key private land conservation practice that needs active stakeholder involvement to deliver successful policy design and implementation. In this study we developed a Bayesian Belief Network (BBN) of landholder participation in biodiverse carbon planting schemes to determine factors most likely to influence program participation. An initial conceptual model was developed based on a review of the literature. The model was refined through interviews with participating landholders and other key stakeholders and, finally, parameterised using expert-elicited information. Our results indicate that participation rates are most influenced by program attractiveness and the identified values of co-benefits (such as biodiversity conservation) rather than financial incentives. Scenario evaluation revealed that providing a combination of biodiversity incentives with more flexible permanence options could increase the program adoption rate. Stacking or bundling credits combined with contract agreements is also likely to increase the participation rate. These findings can assist policy development by focusing on the aspects of policy design most likely to increase participation.

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## 1. Introduction

Biodiversity loss is among the most important ecological issues facing Australia (Hatton et al., 2011; Vancley and Lawrence, 1995). The State of Environment Report 2011 concluded that human activities such as land clearance and population growth are the primary factors responsible for the situation (Hatton et al., 2011). Currently, public conservation areas encompass one-third of Australia but are not considered adequate to conserve biodiversity given their size and the ecological communities they represent (Cowell and Williams, 2006). Therefore, programs for conserving and increasing biodiversity on private land require greater attention and the participation of landholders in these programs is essential (Stephens, 2001).

Biodiverse carbon planting is a key private land conservation practice that has the potential to stimulate investment in biodiversity conservation alongside carbon sequestration. In addition to storing carbon, tree planting has the potential to preserve vital ecological processes and provide suitable habitat for wildlife (Bauhus et al., 2010; Campos et al., 2005; Carswell and Burrows, 2006). Biodiverse plantations will potentially increase the availability of resources for native animals, function as seed banks and enhance the resilience of the ecosystem against climate change and pest invasion (Crossman et al., 2011; Pearce, 2005). Such plantations can be incorporated into existing farming systems through wind breaks, riparian zones and native woodland plantations (Sabto and Porteous, 2011).

### 1.1. Participation rates of landholders in biodiverse carbon programs

Policy-makers in natural resource management are concerned about participation rates in environmental programs (Mettepenningen et al., 2013). In many cases the number of participants has a direct impact on the expected environmental outcomes of the program. In particular, the number of landholders participating in carbon and biodiversity related programs directly influences the objectives of carbon abatement and improvements to biodiversity. Thus, if favourable to landholders, biodiverse carbon planting schemes have great potential to lead to large scale landscape restoration and carbon sequestration (Lin et al., 2013). Like many carbon planting schemes (and other market-based instruments), biodiverse carbon planting schemes rely on financial incentives to achieve higher participation rates among landholders (Hecken and Bastiaensen, 2010; Rode et al., 2015). However, the conservation outcomes of these schemes may also provide an incentive to landholders (Pascual and Perrings, 2007).

The Carbon Farming Initiative (CFI) was introduced in Australia in 2011 to assist in the achievement of a five percent greenhouse gas abatement target by 2020 (Besley et al., 2014) and offers landholders an opportunity to sell sequestered carbon (Australian Government, 2013). Bio-sequestration (e.g. biodiverse carbon planting) is one of the approved methodologies within the initiative (Australian Government, 2014a,b). The CFI is currently in a transitional period (Australian Government, 2014a,b). Hence, it is timely to review carbon farming programs with a view to identifying approaches that could better achieve objectives for carbon abatement, biodiversity conservation and landholder engagement.

Landholder participation rates depend on many social and environmental drivers (Bacon et al., 2002), some of which are independent of scheme design. Examples include the compatibility of programs with the primary land management practices of landholders (Pannell et al., 2006) and the awareness and values of the environmental and productivity benefits of the scheme (Balderas Torres et al., 2015; Jellinek et al., 2013). Existing social networks and the presence of trusted peers within a scheme could also increase participation rates (Sharp et al., 2013; Bodin et al., 2006; Torabi et al., 2016). This is because landholders can observe what is involved in the adoption phase and participation outcomes experienced by their peers (Kueper et al., 2013). Active engagement in local “Landcare” groups also provides social learning opportunities that appear to increase participation in agri-environmental schemes (Sobels et al., 2001). In addition, participation in other conservation programs develops skills and knowledge (Pannell and Wilkinson, 2009) and progresses emergent stewardship values (Gill, 2013) that assist landholders to engage in biodiverse carbon planting schemes.

Specific characteristics of biodiverse carbon sequestration schemes can also affect participation rates and implementation success. Of these, transaction costs are particularly influential (Coggan et al., 2013); a complicated administration process typically reduces landholders’ willingness to become involved. Understanding those processes is resource-consuming for participants, in terms of both time and money (Cocklin et al., 2007). The management requirements of a scheme are another important factor, as high management requirements could negatively impact participation rates (Coggan et al., 2013). In addition, the legal obligation of carbon planting schemes that requires the trees to stay on properties for 100 years (Bradshaw et al., 2013) may reduce landholder willingness to join a scheme, especially in traditional farming landscapes, where landholders might be concerned about the financial implications of revegetation, including impacts on property values (Lokocz et al., 2011).

Financial incentives could assist landholders with establishment and ongoing management costs. Such incentives can be introduced in a range of ways to compensate for the loss of income associated with land use change and thus increase the program uptake rate (Pannell et al., 2006; Pannell and Wilkinson, 2009). Different methods to financially incentivise landholders’ participation in biodiverse carbon plantings exist. These include bundling or stacking carbon and biodiversity credits (Deal et al., 2012; Turner et al., 2014). Bundling entails selling the credits resulting from the carbon plantings in the carbon market, but with the possibility of charging a greater price, as they could be sold as “premium carbon credits” due to the biodiversity co-benefits; therefore, the bundled credits cannot be sold separately in the relative markets. This also

provides buyers in the market with the opportunity to achieve other objectives such as environmental marketing (Bekessy and Wintle, 2008). The stacking of credits enables landholders to sell the carbon and biodiversity credits generated from the same carbon planting separately in both carbon and biodiversity markets (Deal et al., 2012; Lee et al., 2013). Thus stacked carbon and biodiversity credits may be sold once in a biodiversity market, for example as a biodiversity offset, and then again in a carbon market as a carbon credit. However, issues around ‘additionality’ could be a barrier to introducing a market for stacked carbon and biodiversity credits due regulatory requirements (Torabi and Bekessy, 2015). This is because the carbon and biodiversity markets each require that the benefits are “additional” to what would have happened without the carbon plantings (Torabi and Bekessy, 2015). In addition to monetary incentives, existing financial resources available for landholders, such as off-farm income, could also affect participation (Freyer et al., 2014; Raymond and Brown, 2011).

In this paper, we aim to develop a Bayesian Belief Network (BBN) model to predict the likely participation rate of different types of biodiverse carbon sequestration programs when applied to diverse cohorts of landholders.

## 1.2. Bayesian Belief Networks

Bayesian Belief Networks (BBNs) are tools used for decision-making under uncertainty in many fields, including natural resource management, and are particularly useful when combining qualitative and quantitative data (Smith et al., 2012). They are based on probability distribution modelling (Aalders, 2008) and are able to represent causal relationships among variables via an influence diagram (Haines-Young, 2011). BBNs are also useful in supporting policy decision-making and incentive scheme design by identifying key nodes and links that drive program outcomes (McCloskey et al., 2011).

BBNs are often used in Environmental Decision Support Systems because of their ability to work with interlinked factors and because their graphical representation makes the underlying model easy to communicate to stakeholders (Burgman et al., 2010; Henriksen et al., 2007). In addition, the ability of BBNs to undertake both future forecasting and current situation analysis makes them applicable to a variety of contexts and socio-ecological systems (Liedloff and Smith, 2010; Haines-Young, 2011). The flexibility of BBNs to be modified and validated as new data becomes available has also made them practical decision making tools (Smith et al., 2007).

Several studies have employed BBNs to integrate various combinations of social, ecological and economic factors to tackle ecological problems. For example, to manage ground water contamination in Denmark, Henriksen et al. (2007) considered the values and interests of different stakeholders (e.g. farmers and hydrologists) while integrating ecological and economic factors such as surface water quality and the economic viability of farms. In this context, they applied BBNs as a decision support system for “Public participatory modelling” (Henriksen et al., 2007, p.1101). In another example, Johnson et al. (2010) used a BBN to integrate ecological (population size), social (neighbour support) and institutional (e.g. government support) factors to develop a relocation model for a vulnerable cheetah population in Africa. They argued that BBNs not only revealed the most influential factors but also were powerful communication tools that facilitated cooperation among different stakeholders.

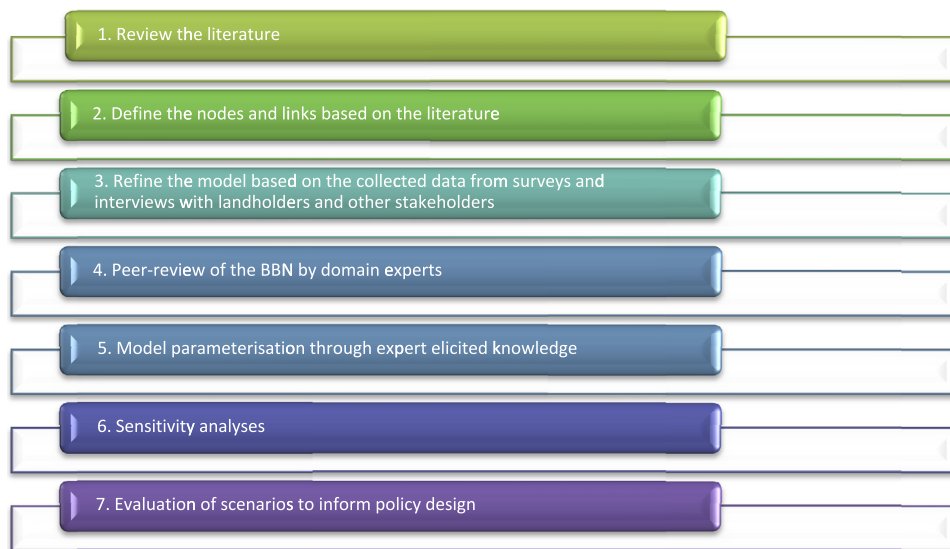
Using expert-elicited knowledge to refine and parameterise BBNs is gaining momentum in conservation science (Kuhnert et al., 2010; Martin et al., 2012). This is due to the urgency and uncertainty (lack of adequate empirical data) involved in making decisions in environmental management (Kuhnert et al., 2010) and the fact that obtaining adequate data to parameterise BBNs can be resource intensive. When warranted, BBNs allow expert-elicited data to be combined with empirical data, exploiting the full potential of the modelling flexibility associated with BBNs (Chen and Pollino, 2012).

We aimed to investigate how landholder participation in biodiverse carbon planting schemes could be increased by considering the socio-cultural drivers of landholders, program design, and the availability of financial resources. We developed a Bayesian Belief Network model based on a review of the literature and findings from interviews with and surveys of landholders, policy-makers and academics, which was further refined and parameterised through expert-elicited knowledge. Our study explored the factors that had the strongest influence on landholders’ participation rate, with important implications for the design and implementation of policies relating to biodiverse carbon plantings. Our study may further contribute to addressing the paucity of program design research in the broader field of environmental planning.

## 2. Materials and methods

We used Bayesian Belief Networks (BBNs) to explore the causal relationships between social and cultural variables that affect a landholder’s decision to participate in biodiverse carbon plantings. A BBN is structured by nodes, representing the model’s variables, and arcs or links, representing the cause–effect links between nodes; the nodes and arcs together form a directed acyclic graph or influence diagram (Jensen and Nielsen, 2007). Each node is attached to a Conditional Probability Table (CPT) in which probabilities are used to describe the degree of belief that the node will be in a particular state given the states of the nodes it is linked to (Chen and Pollino (2012) and Pollino et al. (2007).

In Section 2.1, we discuss the steps undertaken to develop our BBN model of landholder participation rates, which are represented visually in Fig. 1 (each step is further unpacked in Sections 2.1.1–2.1.4). The BBN was developed using the software Netica™ version 5.15 (Norsys, 2007).



**Fig. 1.** Steps undertaken to develop and run the BBN model to test policy implications.

## 2.1. A BBN model of landholder participation

### 2.1.1. Steps one and two: review the literature and define the preliminary nodes and links

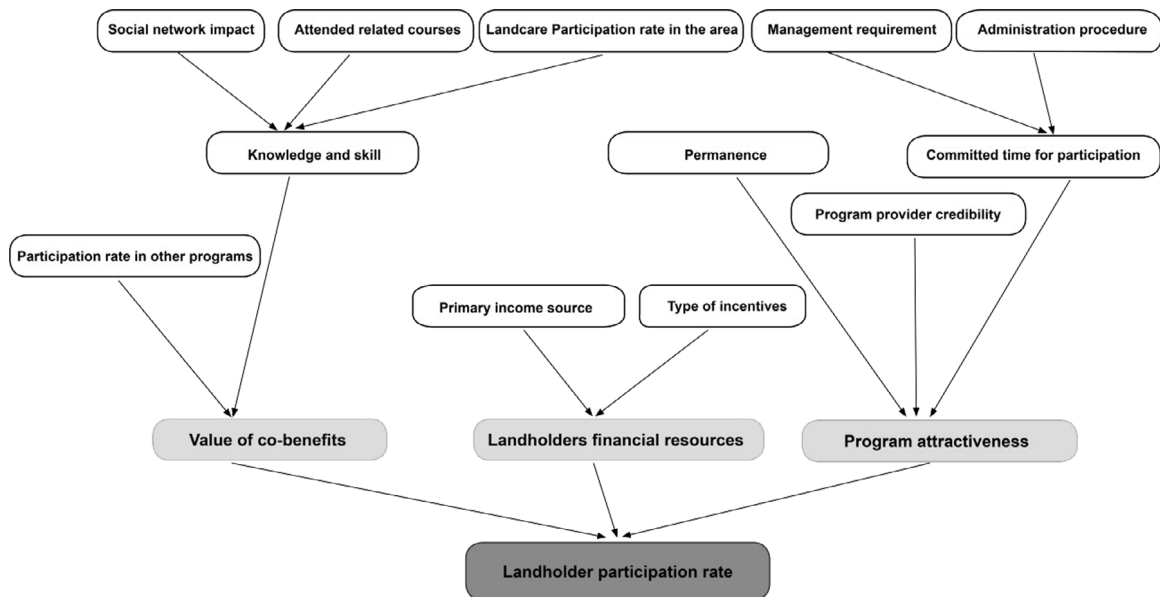
To develop our BBN we first constructed a conceptual model based on a review of the literature. Relevant peer review articles were retrieved by searching for 'landholder participation in private land conservation', 'agri-environmental schemes', 'incentives', 'characteristics of landholders', 'ecosystem management', 'carbon payment', 'voluntary carbon offset', 'land use', 'socio-cultural drivers', 'landholder participation', 'biodiversity conservation' and 'biodiverse carbon planting' in the Web of Knowledge, Scopus and Google Scholar online databases. We also reviewed the original papers cited by these articles. The major drivers of landholder participation that emerged from this review were stewardship (Gill, 2013), social networks (Bodin and Crona, 2009), social learning (Kueper et al., 2013), and participation in 'Landcare' programs (Compton and Beeton, 2012). Based on these themes, the model's preliminary nodes were defined and linked to generate an initial landholder participation conceptual model.

### 2.1.2. Step three: refine the model

The conceptual model was refined using data collected during surveys and interviews with landholders and other stakeholders, such as scientists and policy experts. An initial survey was sent to 47 landholders who had previously participated in a voluntary biodiverse carbon planting scheme in Victoria, Australia. This particular scheme was coordinated by Greenfleet, a not-for-profit environmental organisation that aims to offset greenhouse gas emissions by designing and executing biodiverse tree plantings across Australia (Greenfleet, 2012). We then interviewed all survey respondents ( $n = 17$ ) who were willing to participate in face-to-face conversations on their properties. We also conducted interviews with academics and policy makers actively working in the field of carbon and biodiversity ( $n = 14$ ). Details of this study are provided in Torabi and Bekessy (2015). During the interviews, opinions were sought regarding the status quo, bundling and stacking options for carbon and biodiversity credits, where 'status quo' refers to the current carbon market policy in Australia in which carbon-only payments are offered to landholders. The aim here was to understand the challenges and opportunities with various scenarios with respect to incentivising landholders to participate in biodiverse carbon plantings.

Three categories that may potentially influence landholder participation in biodiverse carbon planting emerged from this data. The first category included landholders' socio-cultural drivers and farm-related factors. This includes intrinsic motivation for biodiversity conservation and farm-related benefits that are influenced by participation in other conservation programs, presence of related skills and knowledge and the impact of social networks and Landcare membership. The second category was related to elements within the policy and program design that impacted either a landholder's decision to participate in a scheme or their experience of participating. These elements included the time commitment required for participation, credibility of the institution that delivers the program, and whether the program contained a permanence rule (requiring 100-year agreement to maintain the plantings). The third category related to the existing landholder financial resources and different incentivising scenarios that make participation affordable, including monetary factors such as financial incentives (e.g. stacking, bundling and status quo) and type of income (e.g. off-farm income).

Survey and interview findings were combined with the findings of the literature review to develop an updated BBN, which was further developed and agreed upon in an expert workshop as described in Section 2.1.3. The description of the



**Fig. 2.** Influence diagram depicting the causal web of key correlates affecting landholder participation rate. The left side branch of the model indicates landholders' social drivers, the middle branch indicates financial factors and the right-hand branch refers to the specific elements of the program. The dark grey node indicates the output node. Landholder participation rate refers to the proportion of landholders in a given region who are likely to agree to participate.

final model's nodes, description, state and the source of factor and the step in which the factor is introduced to the model is given in [Table 1](#).

#### 2.1.3. Steps four and five: peer-review of the BBN by domain experts and model parameterisation through expert-elicited knowledge

A formal peer-review of the refined literature-based BBN was undertaken by two experts during a one-day workshop in October 2014. Both experts were practitioners with extensive experience in working with landholders and different biodiverse carbon planting programs. Our experts had extensive experience engaging landholders in private land conservation schemes in Australia.

The initial step was to specify the objective of the BBN model in greater detail: to understand the influences of different factors on landholder participation in biodiverse carbon planting (applicable to both voluntary and regulated schemes) on ecologically and biophysically viable land under current carbon market and political settings in Australia. Next, the experts were presented with the opportunity to discuss and suggest ways to improve the refined literature-based BBN. During the workshop, the facilitators continually incorporated changes to the model's structure until experts and facilitators agreed on a final BBN that they felt was a good representation of current knowledge about landholder participation rates in biodiverse carbon schemes. This included the addition of one factor, credibility of a program provider. The model's influence diagram is illustrated in [Fig. 2](#) and the description of each node is described in [Table 1](#).

Once experts had reached consensus about the structure of the BBN model, we parameterised each conditional probability table (CPT) by eliciting probabilities from the experts, following guidelines provided by [Kuhnert et al. \(2010\)](#), [Martin et al. \(2012\)](#) and [McBride and Burgman \(2012\)](#). In order to familiarise experts with the elicitation process, we conducted a trial elicitation prior to running the formal parameterisation of the landholder participation rate model.

Following [Burgman et al. \(2011\)](#) and [Martin et al. \(2012\)](#), we designed our elicitation process such that it: (1) required minimum statistical and probability knowledge from participants; (2) applied direct questioning techniques; and (3) accounted for possible bias in the answers. We used a face-to-face Delphi technique to elicit the probabilities for each node's CPT, providing experts with an opportunity to discuss their responses and change their estimates ([Martin et al., 2012](#); [Speirs-Bridge et al., 2010](#)). We asked experts to give us one consensus probability for each cell in the CPT. All of the expert-parameterised CPT tables is provided in the online supplementary materials (see [Appendix A](#)).

#### 2.1.4. Steps six and seven: sensitivity analyses and evaluation of scenarios

We used sensitivity analysis to evaluate the final BBN model. This analysis was undertaken to assess how the 'Landholder participation rate' output node varied as the state of each node in turn was altered between their minimum and maximum ranges while the other nodes were held constant ([Pollino et al., 2007](#), [Korb and Nicholson, 2004](#), [Fenton and Neil, 2013](#)). This allowed us to identify the nodes with the greatest influence on the 'Landholder participation rate' output node. We also used the 'sensitivity to findings' function in Netica™ to corroborate the results from the sensitivity to parameters analysis.



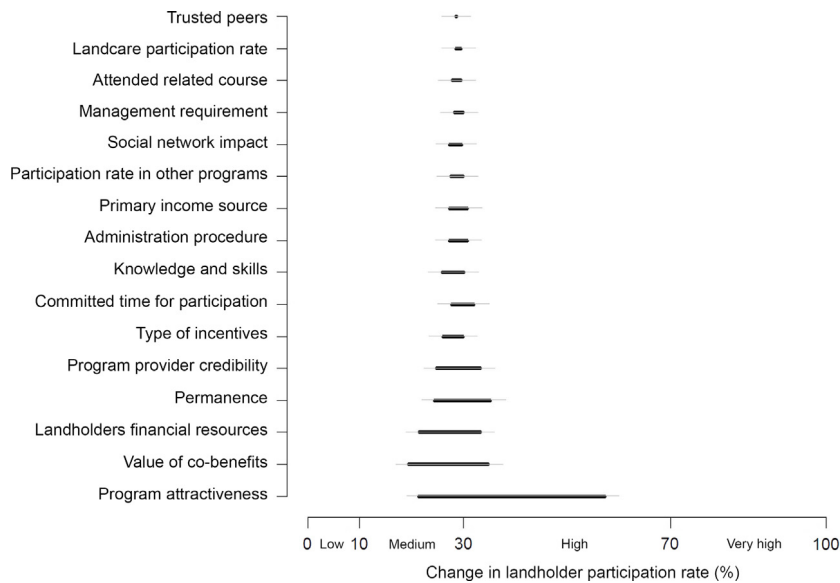
**Table 1**

Description of each node of the BBN, the potential states for each node and relevant data sources. The Description column explains each node, the States column describes different modes that variables can have and the Source column outlines how each node was added to the model, whether through literature review, survey, and interview or expert workshops. State of the output node (Landholder participation rate) was also defined during the expert elicitation workshop: low (0%–10%), medium (10%–30%) high (30%–70%) and very high (over 70%).

Node	Description	States	Data source
Program attractiveness (composite attribute of other nodes)	To what degree a program is attractive to landholders	High, medium, low	Survey and interview
Value of co-benefits (composite attribute of other nodes)	The conservation and non-conservation (productivity related) recognition of co-benefits of carbon planting by landholders	Conservation, non-conservation and none	Literature (Jellinek et al., 2013; Saunders and Walker, 1998), survey and interview
Landholders' financial resources (composite attribute of other nodes)	The availability of adequate financial resources (incentives from the scheme and off-farm income) to enable the participation	Present, absent	Literature (Rode et al., 2015), survey and interview
Permanence	The required longevity (duration) of trees remaining on properties	long (100 years), short (25 years), contract (non-binding, no time frame)	Interviews, expert opinion
Credibility of a program provider	Trustworthiness of the program provider to the landholders	High, medium or low	Expert opinion
Type of incentives	Stacking carbon and biodiversity credits, bundling carbon and biodiversity credits or carbon only payments	Stacking, bundling or carbon only	Literature (Deal et al., 2012), interviews
Knowledge and skill	The required skills to undertake biodiverse carbon plantings	Extensive, moderate or limited	Literature (Davidson-Hunt, 2006; Pannell et al., 2006), interviews
Primary income source	Off-farm, on-farm or both	Off-farm, on-farm or both	Literature (Raymond and Brown, 2011), survey and interview
Committed time for participation	The amount of time needed to go through the administration process and undertake management of carbon plantings	Extensive, moderate or limited	Literature (Pannell et al., 2006), survey and interview
Participation in other conservation programs	If landholders are participating in any other private land conservation (PLC) programs such as Trust for Nature and Land for Wildlife	High (more than 5), medium (2–4) or low (1 or less program)	Survey and interview
Administration procedure	The time required to obtain information, make sense of the scheme and go through the administrative process	Highly complicated (requires more than a week), moderate (requires a few days) or straightforward (requires less than a day)	Survey and interview
Social network impact	The strength of social networks in their community, how well connected they are	Strong, medium or weak	Literature (Bodin and Crona, 2009; Bodin and Prell, 2011), survey and interview
Attended related courses	Any CMA, TAFE or university program attended related to conservation or sustainable land management	Yes or no	Survey and interview
Management requirement	Fencing, weed and feral animal control, and monitoring required by the scheme	Extensive, moderate or low	Literature (Blackmore and Doole, 2013; Pannell et al., 2006), survey and interview
Landcare participation rate	The percentage of landholders in an area participating in the local Landcare group	High (more than 40%), medium (10%–40%) or low (less than 10%)	Literature (Compton and Beeton, 2012; Martin, 1997; Sobels et al., 2001), survey and interview
Trusted peers	Presence of champions in a community	Present or absent	Literature (Meadows et al., 2013), survey and interview

The function uses entropy reduction to estimate the mutual information value for the each network's node, and expresses this as a percentage of the total entropy of the output node (Korb and Nicholson, 2004; Norsys, 2007; Pearl, 1988; Pollino et al., 2007).

Finally, we estimated the expected landholder participation rate under nine different scenarios representing the various combinations of permanence agreements (100 year, 25 year and on-contract) and financial incentives (stacking credits, bundling credits and carbon only payments) to provide an opportunity to inform policy. These scenarios have implications well beyond the Australian context in which we tested them, as permanence agreements and financial incentives are ubiquitous factors of bio-sequestration schemes worldwide (Torabi and Bekessy, 2015). The nine scenarios are described



**Fig. 3.** A wizard's hat diagram showing the sensitivity of the 'Landholder participation rate' output node to each one of the model's parameters. Black lines indicate the range of the change as the parameter is varied from its lowest to its highest values and grey lines indicate the widest associated 2.5% and 97.5% confidence intervals.

below:

- Scenario 1: stacking credits & 100 year permanence agreement
- Scenario 2: stacking credit & 25 year permanence agreement
- Scenario 3: stacking credits & on-contract permanence agreement
- Scenario 4: bundling credits & 100 year permanence agreement
- Scenario 5: bundling credits & 25 year permanence agreement
- Scenario 6: bundling credits & on-contract permanence agreement
- Scenario 7: carbon only payments & 100 year permanence agreement
- Scenario 8: carbon only payments & 25 year permanence agreement
- Scenario 9: carbon only payments & on-contract permanence agreement.

To test these scenarios, we noted the change in the output node 'Landholder participation rate' as the states of the *permanence* and *financial incentives* nodes were set to their corresponding values. No evidence was entered to the nodes not being evaluated, so they had no influence on the nine scenarios under evaluation. We then imported the BBN model's posterior distributions for each discretised state of the output node into R (R Core Team, 2015) and used them to generate continuous simulated probability density functions for each scenario. This allowed us to estimate the mean and 95% confidence interval for the output node 'Landholder participation rate' under each scenario. These estimations were based on a sample size of 400, which is an estimate of the minimum number of biodiverse carbon planting sites in Australia that the experts are likely to have been exposed to during their professional careers.

### 3. Results

The final BBN model was composed of 14 nodes and 15 arcs (Fig. 2). The names, descriptions, states and data source of all model variables are summarised in Table 1.

#### 3.1. Sensitivity analyses

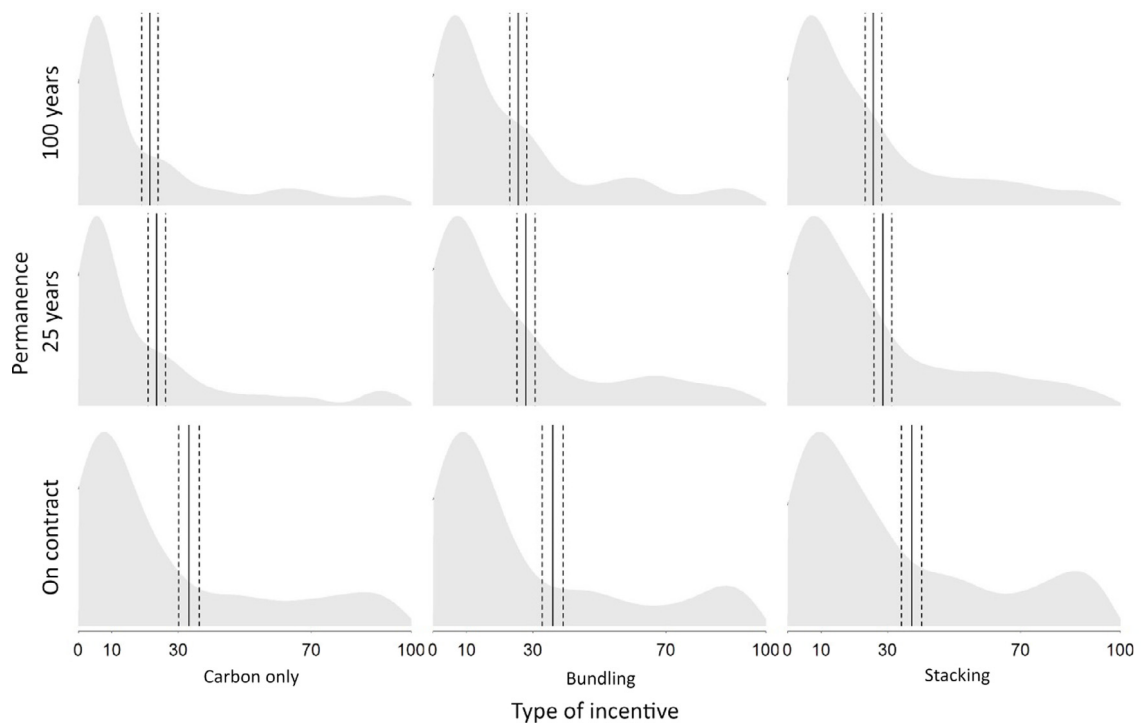
Results from the sensitivity to parameters analysis are shown in Fig. 3. The 'Landholders participation rate' was highly sensitive to nodes directly linked to it. 'Program attractiveness' was the most sensitive node (absolute change in the output variable between its higher and lower states  $[\Delta] = 35.6$ ), followed by 'Value of co-benefits' ( $\Delta = 15.1$ ) and 'Landholders financial resources' ( $\Delta = 11.8$ ). Overall, the sensitivity to parameters analysis confirmed that the model was behaving as expected, with nodes directly linked to the output node having the greatest influence compared to the influence of nodes which were diluted by other nodes (Jellinek et al., 2014; Korb and Nicholson, 2004). These results were in agreement with the sensitivity to findings analysis (See Table 3 in the online supplementary material).



**Table 2**

Estimated mean and 95% confidence interval for 'Landholder participation rate' under each evaluated scenario. Scenario 7 is the status quo.

			Landholder participation rate		
			Confidence interval		
			Mean	Low (2.5)	High (97.5)
Base model			28.8	25.9	31.7
Scenarios					
No.	State of the permanence node	State of the type of incentives node	Mean	Low (2.5)	High (97.5)
1	100-year agreement	Stacking carbon and biodiversity credits	26.5	23.9	29.1
2	25-year agreement	Stacking carbon and biodiversity credits	28.1	25.5	30.1
3	On-contract agreement	Stacking carbon and biodiversity credits	37.7	34.6	40.7
4	100-year agreement	Bundling carbon and biodiversity credits	25.1	22.6	27.5
5	25-year agreement	Bundling carbon and biodiversity credits	27.3	24.6	30
6	On-contract agreement	Bundling carbon and biodiversity credits	36	33	39
7	100-year agreement	Carbon only payments	22.1	19.6	24.6
8	25-year agreement	Carbon only payments	24	21.4	26.5
9	On-contract agreement	Carbon only payments	32.6	29.5	35.6



**Fig. 4.** Simulated 'Landholders participation rate' continuous probability density function for each evaluated scenario (grey shaded areas). Scenarios are a combination of the type of incentives (x-axis) and the permanence of the agreement (y-axis). Black solid lines represent 'Landholders participation rate' mean responses, and dotted lines represents the associated 95% confidence intervals. A complete description of each scenario is given in [Table 2](#).

### 3.2. Scenario evaluation: considering different options for contract permanence and financial incentives

We tested multiple scenarios for landholder participation rates that modify the permanence rules and financial incentives. The deviation of each scenario from the neutral model is shown. The estimated 'Landholder participation rate' mean and 95% confidence interval for each evaluated scenario are presented in [Table 2](#). Likewise, for each scenario, the simulated 'Landholders participation rate' continuous probability density function is shown in [Fig. 4](#). Stacking carbon and biodiversity credits and on-contract agreement (Scenario 3) are the most effective options (mean 37.7 and CI 34.6–40.7%), followed by scenario 6, bundling credits and on contract arrangements (mean 36 and CI 33–39%). The scenario evaluation also revealed that the status quo (scenario 7), where a sole payment for carbon credits is offered to landholders with a long-term agreement option, reduces the participation rate substantially and it is the least effective scenario (mean 22.1 and CI 19.6–24.6%). The most attractive scheme is likely to offer contract participation, rather than a set timeframe committing participants. However, the difference between shorter (25 year) and longer term (100 year) agreements was trivial.

#### 4. Discussion

We developed a Bayesian Belief Network of landholder participation rates based on a review of the literature, interviews with landholders and other stakeholders, and expert elicitation. Our model focused on three main factors that impact the uptake of biodiverse carbon planting schemes by landholders: the value of co-benefits, program attractiveness and availability of financial incentives for landholders. Results from our BBN model indicate that the rate of landholder participation is most sensitive to changes to program attractiveness, driven by factors describing the permanence of the planting and the credibility of the program providers. Hence, focusing design of programs towards elements that make programs appealing has the potential to improve uptake by landholders. A key element to consider in this context is introducing some flexibility to permanence rules. Furthermore, policies should be designed to fit a broader audience in rural communities, including different options for commercial farmers looking for productivity benefits and life-style landholders seeking aesthetic amenities. In addition, a credible program provider that has a good reputation in the community or supporting the existing landholder co-operatives could increase the success of biodiverse carbon planting schemes.

Our findings suggest that important social factors are key to the success of biodiverse carbon planting programs. The value of conservation and non-conservation related co-benefits among landholders were shown to potentially influence program adoption. This awareness occurs as landholders learn through their social networks (including friends, family, and neighbours) and attend land management-related courses to develop their knowledge and skills. Participation rates in other private land conservation programs, for example, Land for Wildlife (providing habitat for native wildlife) ([Department of Environment and Primary Industry, 2015](#)) could assist with knowledge development and emergent land stewardship values, although this variable did not emerge as a strong driver in our study. These factors have an impact on both the productivity drivers such as pasture improvement and establishment of windbreaks, and conservation-oriented drivers, including improving wildlife corridors and conserving biodiversity.

We explored scenarios that provide different financial incentives to landholders including stacking, bundling and payments for carbon credits. Although financial incentives have been shown to assist landholders with establishment, management and monitoring expenses ([Cacho et al., 2013](#); [Crossman et al., 2011](#); [Galik et al., 2012](#)), our research supports previous findings that these incentives are not the main factor affecting program uptake (e.g. [Kragt et al., 2014](#)). Stacking credits, for example, had the potential to increase participation rates in biodiverse carbon plantings. However, considering the additional hurdles of the carbon and biodiversity markets, it seems more practical to consider the option of bundling carbon and biodiversity credits. This could be introduced as a premium carbon standard, offering higher pricing to recognise the biodiversity co-benefits of carbon plantings and assist landholders with the transaction costs.

We also explored how financial incentives interact with permanence to influence participation rates in biodiverse carbon schemes. Stacking or bundling together with a less rigid agreement is likely to make a policy more attractive, achieving higher adoption rates among landholders. A flexible carbon farming scheme not only provides different options but will be straightforward to monitor, review and improve based on the landholders' demands and the global carbon market ([Besley et al., 2014](#)). While our BBN was based on data collected in the Australian context, the findings have a much broader application. Financial incentives and permanence are elements of all biodiverse carbon planting programs, hence our findings have applications in many different parts of the world.

In this study, we demonstrated the application of an expert-parameterised BBN to predict the likelihood of landholders' participating in biodiverse carbon plantings. We have highlighted their value as a conservation tool, especially in addressing the uncertainty associated with developing environmental management policy when empirical data are lacking. It is important to acknowledge, however, that our BBN model is only an approximation of the network of causal variables influencing landholders' participation in biodiverse carbon plantings. A more precise network could be produced, perhaps, by developing the model with empirically derived data. In our study, however, no empirical data was available. We therefore had to rely on carefully elicited expert information to elucidate the aspects of landholder environmental policy design most likely to increase participation in biodiverse carbon schemes. We also acknowledge that our model was primarily aimed at understanding how to improve participation rates, rather than how to produce the best conservation or carbon sequestration outcomes. While we found that flexibility in permanence increases participation rates, this may come at the expense of long-term security of conservation (or carbon sequestration) gains. This trade-off would be important to explore in future research.

We acknowledge some limitations to the present study. First, our data were drawn from a relatively small sample; a larger sample size could contribute to improved accuracy of the model. However, while small in number, our interviews captured a wide diversity of participants (both landholders and other stakeholders). Second, many interpersonal characteristics of landholders that fell outside the scope of this study may also affect participation rates. Third, future studies may benefit from exploring the barriers to adoption of these programs as seen by non-participants of the program. Finally, our model was developed exclusively for the current carbon market political setting.

#### 5. Conclusions

Increasing landholder participation rates is, arguably, one of the most important factors leading to the achievement of the landscape scale biodiversity conservation and carbon abatement goals typically stated by biodiverse carbon planting schemes. Results from our study indicate that higher adoption rates depend on the design of programs and the value

of co-benefits, as perceived by the landholders. Stacking and bundling credits with a more flexible permanence option have the potential to increase the likelihood of landholders participating in biodiverse carbon schemes. Hence, a more flexible program design that offers different options for landholders to choose from, based on their own knowledge and available resources (e.g. time) seems to provide the optimal scenario for improving landholder participation rates. Furthermore, programs should ensure that the landscape-specific co-benefits of participation are effectively communicated to landholders.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found online at <http://dx.doi.org/10.1016/j.gecco.2016.03.008>.

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